Infiltration(I) J. L. McG. +

ARS 41-51
October 1961

A Concept for INFILTRATION ESTIMATES in Watershed Engineering

AGRICULTURAL RESEARCH SERVICE
U. S. DEPARTMENT OF AGRICULTURE

CONTENTS

	Page
INTRODUCTION	1
POTENTIAL VOLUME OF INFILTRATION	2
CAPACITY RATES OF INFILTRATION	10
APPLICATION OF RESULTS	12
LITERATURE CITED	17
APPENDIX	18

A CONCEPT FOR INFILTRATION ESTIMATES IN WATERSHED ENGINEERING

H. N. Holtan [1]

INTRODUCTION

The infiltration capacity of a soil as it changes with continuing rainfall is a most important estimate in computing the hydrologic performance of watersheds. Many of the designs developed in watershed engineering are based upon man's ability to modify the infiltration capacities of the various soils within the watershed. The hydrograph of runoff is greatly influenced by infiltration. A dependable system is needed for associating the infiltration curve with characteristics of the plant cover and the soil profile. The concepts presented in this paper offer some new avenues of approach.

As reviewed by Philip (7) [2], the classic equations of Horton and Kostiakov require knowledge of the initial rate of infiltration and compute deceleration as a function of time to derive the curve of infiltration. A modest error in the estimate of the initial rate or in its deceleration can result in serious miscalculations of infiltration amounts, especially for larger periods of time. Philip (7) developed an equation with time as the dependent variable (i.e., the rate of infiltration a function of cumulative infiltration) but abandoned it, because of its unwieldiness, in favor of an equation for computing the infiltration rate as a function of time with sorption and permeability as parameters. Sorptivity is defined by Philip as the capacity to absorb or desorb liquid by capillarity.

This paper proposes a concept for estimating a potential volume of infiltration from characteristics of the soil and subsequently providing a shape to the curve of progress toward this total. The rate of infiltration is herein considered to be a function of the remaining volume of potential storage above the confining horizon and the permeability of the confining horizon. Time is therefore a dependent variable, which is a function of the volume increment and the associated rate. The unwieldiness encountered by Philip is not dispelled but the technique is demonstrated by simple sequences of computations.

An array of prominent soils in the United States prepared by G. W. Musgrave (6) provides a means of evaluating the constant rate of infiltration after the soil is thoroughly wetted. Since Musgrave derived his estimates of infiltration from watershed hydrographs wherein quick-return

---

[1] Director, U. S. Hydrograph Laboratory, Northeast Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

[2] Numbers in parentheses refer to Literature Cited at the end of this report.

flow is indistinguishable from surface runoff, his estimates of final rate of infiltration approximate the permeability of the least permeable horizon reached. There remains, however, the problem of estimating the volume and rate of infiltration preceding this constancy. An infiltrometer survey of two small watersheds in Illinois in 1940 (8), although not designed for this purpose, provides some data suitable for preliminary exploration of this aspect. The symbols used in this discussion are given as footnotes to table 1.

POTENTIAL VOLUME OF INFILTRATION

The volume of infiltration, which occurred before the rate of infiltration became constant, was determined with an infiltrometer for various antecedent moisture contents on plots selected to represent the diversity of soils and vegetation found on the Edwardsville, Ill., watersheds. Figure 1 portrays a "run" typical of those made on 6 - by 12-foot rectangular plots with a type "F" infiltrometer applying about 1.78 inches of water per hour. Data in table 1 are from plots on which: (a) Recurrent runs were made, (b) one type of vegetation predominated, and (c) no unusual condition, such as return flow at some down-slope point, was observed. The volumes of infiltration prior to the time of a constant rate (F, @, f_c), given in the next to the last column of table 1, were derived as illustrated in figure 1.

Although the detail characteristics of soils on these plots are not essential to the portrayal of the concepts presented here, descriptions of typical profiles are as follows:

Plot No. 2 — Alma Silt Loam — Slope 9.62 percent

A- 0" to 7". A light brownish-yellow friable silt loam, with a rather heavy grayish cast especially noticeable when dry. Single grain structure. No. A2 horizon is present, indicating that all the surface soil remaining has been mixed together by cultivation.

B1- 7" to 10". A light brownish-yellow heavy silt loam with slight grayish coatings and some gray mottling.

B2- 10" to 20". A light brownish- to reddish-yellow silty clay loam rather heavily mottled with light gray. Slightly angular aggregates.

C- 20" to 40". A mottled light gray and reddish-yellow heavy silt to silty clay loam, with occasional small pebbles present. Texture is lighter than B2.

TABLE 1.--Infiltration Data, Edwardsville, Illinois (Type "F" Infiltrometer, 6- x 12-foot plot, rainfall 1.78 + inches per hour)

Date	Data 1/	At various hours from start of rainfall 0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	@f_c 2/	S_o 3/
		Plot No. 1: Alfalfa, 11.72% slope, Alma silt loam											
6/17/40	f	1.15	0.94	0.62	0.36	0.24	0.20					0.20	
	F	.30	.60	.99	1.23	1.37	1.57					1.57	3.34
	F_p	1.27	.97	.58	.34	.20	0					0	
7/17/40	f	1.48	1.13	.60	.34	.22	.15					.15	
	F	.37	.74	1.18	1.41	1.55	1.73					1.73	3.62
	F_p	1.36	.99	.55	.32	.18	0					0	
8/30/40	f	.86	.54	.28	.17							.17	
	F	.23	.45	.65	.75							.75	5.43
	F_p	.52	.30	.10	0							0	
6/10/41	f	1.65	1.25	.61	.33	.17	.08	.05	.02	.01		.01	
	F	.40	.80	1.25	1.48	1.60	1.70	1.77	1.80	1.81		1.81	4.40
	F_p	1.41	1.01	.56	.33	.21	.11	.04	.01	0		0	
		Plot No. 2: Alfalfa, 9.62% slope, Alma silt loam											
6/18/40	f	1.18	.88	.46	.28	.24	.22					.22	
	F	.31	.62	.94	1.12	1.26	1.47					1.47	4.53
	F_p	1.16	.8[illegible]	.53	.35	.21							
7/15/40	f	1.56	1.1[illegible]	.59	.39	.28	.21					.21	
	F	.40	.79	1.20	1.45	1.60	1.83					1.83	4.53
	F_p	1.43	1.04	.63	.38	.23	0						
10/16/40	f	.95	.72	.60	.50	.33	.30					.30	
	F	.27	.53	.85	1.08	1.30	1.47					1.47	2.88
	F_p	1.20	.94	.62	.39	.17	0						
6/11/41	f	1.50	1.16	.63	.30	.28	.20	.17				.15	
	F	.38	.75	1.20	1.44	1.59	1.80	1.99				1.99	4.03
	F_p	1.61	1.24	.79	.55	.40	.19						

TABLE 1.--Continued

Date	Data	At various hours from start of rainfall											
		0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	@f_c	S_o
		Plot No. 5: Alfalfa (crabgrass came in after first 1 or 2 runs), 1.22% slope, Bogota silt loam											
6/19/40	f	1.35	0.91	0.47	0.30	0.28						0.28	
	F	.34	.68	1.01	1.20	1.33						1.33	4.21
	F_p	.99	.65	.32	.13	0							
7/19/40	f	1.55	1.24	.71	.44	.36	.30 e[4]/					.30	
	F	.39	.78	1.27	1.53	1.74	2.05					2.05	6.23
	F_p	1.66	1.27	.78	.52	.31	0						
10/29/40	f	1.46	1.23	.88	.62	.44	.36					.36	
	F	.38	.75	1.27	1.61	1.87	2.24					2.24	3.96
	F_p	1.86	1.49	.97	.63	.37	0						
6/20/41	f	1.57	1.15	.60	.44	.35	.26					.26	
	F	.40	.79	1.20	1.72	2.11	2.41					2.41	4.63
	F_p	2.01	1.62	1.21	.69	.30	0						
		Plot No. 6: Alfalfa (crabgrass came in after first 1 or 2 runs), 1.00% slope, Bogota silt loam											
6/20/40	f	1.46	1.10	.65	.49	.33						.33	
	F	.36	.73	1.15	1.43	1.64						1.64	4.74
	F_p	1.24	.91	.49	.21	0							
7/23/40	f	1.76	1.67	1.22	.87	.70	.58	.50				.50	
	F	.42	.85	1.62	2.12	2.52	3.13	3.67				3.67	5.43
	F_p	3.25	2.82	2.05	1.55	1.15	.54	0					
9/13/40	f	1.52	1.14	.67	.51	.42	.33					.33	
	F	.38	.75	1.18	1.49	1.70	2.04					2.04	3.75
	F_p	1.66	1.29	.86	.55	.34	0						
6/18/41	f	1.48	1.15	.71	.56	.48	.39	.32	.27	.24		.24	
	F	.38	.75	1.19	1.52	1.78	2.20	2.56	2.86	3.12		3.12	3.38
	F_p	2.74	2.37	1.93	1.60	1.34	.92	.46	.26	0			

TABLE 1.--Continued

Date	Data	At various hours from start of rainfall											
		0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	@f_c	S_o
		Plot No. 7: (Lespedeza & timothy pasture lightly grazed), 1.36% slope, Bogota silt loam											
6/25/40	f	1.18	0.83	0.58	0.52	0.49	0.46					0.46	
	F	.31	.62	.98	1.25	1.49	1.95					1.95	5.33
	F_p	1.64	1.33	.97	.70	.46	0						
7/29/40	f	1.53	1.32	1.04	.82	.67	.51	.46				.46	
	F	.39	.77	1.36	1.84	2.21	2.78	3.26				3.26	6.81
	F_p	2.87	2.49	1.90	1.42	1.05	.48	0					
9/18/40	f	1.29	.99	.63	.52	.47	.36					.36	
	F	.32	.63	1.08	1.38	1.63	2.04					2.04	4.36
	F_p	1.72	1.41	.96	.66	.41	0						
		Plot No. 8: (Lespedeza & timothy pasture lightly grazed), 1.30% slope, Bogota silt loam											
6/26/40	f	1.45	1.22	.90	.66	.54	.52					.52	
	F	.37	.74	1.26	1.65	1.95	2.45					2.45	5.63
	F_p	2.08	1.71	1.19	.80	.50	0						
8/1/40	f	1.59	1.43	1.17	.95	.77	.57					.57	
	F	.39	.78	1.44	1.98	2.40	3.05					3.05	6.35
	F_p	2.66	2.28	1.61	1.07	.65	0						
11/7/40	f	.87	.76	.65	.54	.48	.46					.46	
	F	.24	.47	.83	1.13	1.39	1.85					1.85	4.99
	F_p	1.61	1.38	1.02	.72	.46	0						
6/27/41	f	1.64	1.48	1.17	.91	.78	.66	.60	.54	.47	.35	.30	
	F	.41	.82	1.50	2.01	2.43	3.09	3.72	4.28	4.78	5.19	5.19	5.30
	F_p	4.78	4.37	3.69	3.18	2.76	2.01	1.47	.91	.41	0		

TABLE 1.--Continued

Date	Data	At various hours from start of rainfall											
		0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	$@f_c$	S_o
Plot No. 11: Bluegrass 50 yrs., 1.25% slope, Bogota silt loam													
7/1/40	f	1.74	1.69	1.54	1.30	0.76	0.23	0.21				0.21	
	F	.42	.85	1.70	2.40	2.95	3.35					3.35	4.03
	F_p	3.13	2.70	1.85	1.15	.60	0						
8/7/40	f	1.82	1.81	1.78	1.52	.78	.24	.17	.15[e]			.15	
	F	.46	.92	1.83	2.54	3.24	3.65	3.85	4.00			4.00	3.09
	F_p	3.54	3.08	2.17	1.46	.76	.35	.15					
9/30/40	f	1.80	1.70	1.53	1.42	1.30	1.04	.57	.23	.14	.10	.10	
	F	.45	.90	1.70	2.42	3.10	4.30	5.03	5.43	5.60	5.72	5.72	4.42
	F_p	5.27	4.82	4.02	3.30	2.62	1.42	.69	.29	.12	0		
7/8/41	f						1.38	.53	.24	.11	.09	.09	
	F						5.25	6.70	7.18	7.38	7.48	7.48	6.37
	F_p						2.23	.78	.30	.10	0		
Plot No. 12: Bluegrass 50 yrs., 1.67% slope, Bogota silt loam													
6/5/40	f	1.47	1.22	1.00	.84	.55	.06					.03	
	F	.37	.74	1.27	1.75	2.10	.38					2.43	3.81
	F_p	2.06	1.69	1.16	.68	.33	.05						
7/2/40	f	1.74	1.68	1.49	1.25	.88	.32	.22				.22	
	F	.44	.87	1.68	2.38	2.92	3.47	3.72				3.72	4.98
	F_p	3.28	2.85	2.04	1.34	.80	.25	0					
8/9/40	f			1.79	1.12	.52	.16					.16	
	F			1.70	2.10	3.01	3.29					3.29	2.76
	F_p			1.59	1.19	.28	0						

TABLE 1.--Continued

Date	Data	At various hours from start of rainfall											
		0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	@f_c	S_o
		Plot No. 12 (Continued): Bluegrass 50 yrs., 1.67% slope, Bogota silt loam											
11/20/40	f	1.50	1.39	1.17	1.09	.99	.73	.48	.30	.18	.10	.08	
	F	.39	.77	1.39	1.94	2.46	3.35	4.15	4.55	4.81	4.99	4.99	4.36
	F_p	4.60	4.22	3.60	3.05	2.53	1.64	.84	.44	.18	0		
7/10/41	f					1.78	.88	.26	.12	.10		.10	
	F				2.64	3.50	4.96	5.63	5.81	5.92		5.92	5.15
	F_p					2.42	.96	.29	.11	0			
		Plot No. 15: Weeds, pasture, 12.11% slope, Elco silt loam											
7/10/40	f	1.32	0.99	0.57	0.41	0.38						0.38	
	F	.33	.66	1.05	1.29	1.48						1.48	5.23
	F_p	1.15	.82	.43	.19	0							
8/19/40	f	.66	.38	.24	.22							.22	
	F	.18	.35	.51	.62							0.62	3.98
	F_p	.44	.27	.11	0								
12/20/40	f	.25	.12									.12	
	F	.09	.18									0.18	2.96
	F_p	.09	0										
7/21/41	f	.95	.56	.42	.36							.34	
	F	.26	.53	.76	.97							.97	4.53
	F_p	.71	.44	.21	0								

TABLE 1.--Continued

Date	Data	At various hours from start of rainfall											
		0.25	0.50	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	@f_c	S_o
		Plot No. 16: Weeds, pasture, 11.11% slope, Elco silt loam											
7/12/40	f	1.58	1.20	.68	.51	.44	.32					.32	
	F	.39	.78	1.23	1.53	1.76	2.12					2.12	5.79
	F_p	1.73	1.34	.89	.59	.36	0						
8/20/40	f	.57	.37	.22	.17	.15						.15	
	F	.18	.35	.50	.59	.59	.69					0.69	3.14
	F_p	.51	.34	.19	0								
10/11/40	f	.45	.26	.17	.16							.16	
	F	.15	.29	.40	.48							0.48	2.00
	F_p	.33	.19	.08	0								
3/26/41	f	1.30	.94	.61	.36	.26	.18					.18	
	F	.32	.65	1.03	1.27	1.42	1.62					1.62	3.58
	F_p	1.30	.97	.59	.35	.20	0						
7/23/41	f	.83	.56	.43	.39							.39	
	F	.24	.48	.72	.91							0.91	3.38
	F_p	.67	.43	.19	0								

1/ f = Rate of infiltration in inches per hour; F = accumulated infiltration in inches; F_p = potential infiltration to time of (f_c) i.e. S_o-F, in inches.

2/ f_c = Rate at which infiltration steady or nearly so, in inches per hour.

3/ S_o = Available soil porosity at start of rainfall, that is, total porosity - soil moisture in the upper 21 inches of soil.

4/ (e) as an exponent indicates estimated value.

Plot No. 5 Bogota Silt Loam Slope 1.22 percent

A1- 0" to 8". A medium dark yellowish-gray friable silt loam, with a weakly granular structure. It has a loose friable consistency.

A2- 8" to 15". A light yellowish-gray floury silt loam, almost ashy, largely single grain structure.

B1- 15" to 18". A light yellowish-gray heavy silt loam. It has a granular structure. With a brownish-yellow gray color inside the granules and coated with light yellow gray on the outside.

B2- 18" to 30". A light gray clay loam with splotches of reddish-yellow. It is rather compact and plastic with slow permeability.

C- 30" to 40". A light gray silty clay loam mottled with reddish-yellow. It has little structural development, and is lighter in texture than the B2.

Plot No. 15 Elco Silt Loam Slope 12.11 percent (Eroded)

A- 0" to 2". A light brownish-yellow silt loam. A tendency toward lamination. A small amount of clay is present. (This layer consists of a mixture of surface soil and subsoil.)

B1- 2" to 20". A light brownish-yellow silty clay loam, lightly coated and heavily splotched with gray. Subangular aggregates.

C- 20" to 40". A yellowish-gray heavy silt loam, mottled with brownish-yellow, becomes a friable silt loam below 30". Structureless.

The volume of storage available at the start of the run was computed as the difference between total porosity and soil moisture in the 0" to 21" depth. Generally the restricting horizon in these soils is not deeper than 21 inches. The volume of unoccupied porosity above the restricting horizon at the start of the run, (S_o), was computed from antecedent moisture records and total porosity determinations.

By inspection of the last two columns in table 1, it is evident that the available porosity is not always filled before the rate of infiltration becomes constant. The extent to which available porosity is exhausted appears to be a function of the type of vegetation present. The volume of infiltration, which occurred prior to a constant rate is compared with the volume of available porosity for various crops in figure 2. Plots 5 and 6 of figure 2 were originally alfalfa, but after the first infiltrometer run, crabgrass took over to a point where it had to be recognized.

The relationships expressed in figure 2 are not without precedent. Various investigators (1, 3) have found that cropping and depletions in organic matter have an adverse affect on soil porosity. Generally, reductions in total porosity are in the vicinity of 10 percent but reductions in non-capillary porosity are often more than 50 percent. Non-capillary porosity is the network of channels distributing infiltrated water to points from whence it moves by the slower process of capillarity. Reductions in the size, number or efficiency of these aqueducts cause rapidly infiltrating water to bypass a corresponding portion of the capillary porosity. This reduces the portion of available storage that will be filled during a few hours of time (during the course of a rainstorm or irrigation application).

Vegetation is tested here not for predicting available porosity, but as an index of the extent to which available storage will be utilized before the rate of infiltration becomes constant. As a quantitative measurement of this index, the basal area, i.e., the percent of ground surface area occupied by roots or stems, was determined for each plot. Determinations were not made for each run, so they cannot be applied individually; however, the average density for each type of vegetation is presented in table 2. As observed in figure 3, the average percentage of basal area is closely correlated with the average percentage of available porosity filled before the rate of infiltration becomes constant.

It appears that the potential volume (F_p) of infiltration to the time of constant rate can be estimated by applying a percentage (k) based upon vegetation to the initially available porosity (S) above the restricting horizon in the soil. This procedure provides a finite value for reasonable comparison with known features of a soil, and it places a ceiling on the error of estimate.

CAPACITY RATES OF INFILTRATION

The potential volume of initial infiltration (F @ f_c) is of little or no value without some knowledge of the rates at which this volume will accrue. Logically, the capacity rate of infiltration is a function of the unoccupied porosity at a particular time. Therefore, the status of remaining potential infiltration (F_p) was computed in table 1 for comparison with the rate of infiltration. Plottings of rate versus remaining potential volume, on logarithmic coordinates, gave a curved-line relationship, but subtraction of the constant (f_c) gave a straight-line relationship. This relationship is shown in figure 4 for various types of vegetative cover. Infiltration on plots numbers 11 and 12, Bluegrass, was limited by the rate of rainfall. Consequently, the relationship is distorted for the higher rates on these plots and the curve was drawn in with this in mind. The general relationship for all plots is expressed by the formula:

$$f-f_c = aF_p{}^n$$

TABLE 2.--Average basal areas of vegetation on infiltrometer plots

Vegetation	Number in average	Average basal area in percent
Alfalfa - no grass	12	18
Crabgrass and alfalfa	9	62
Weeds	4	10
Bluegrass	11	97
Timothy and lespedeza	5	43

Wherein: f = capacity rate of infiltration in inches/hour.

f_c = constant rate of infiltration in inches/hour.

F_p = potential infiltration to time of constant rate and $\underline{a}$ and $\underline{n}$ are constants for a given soil-vegetation complex.

The value of $\underline{n}$ was essentially equal to 1.387 for all 4 curves. The value of $\underline{a}$ ranges from 0.25 to 0.80 with no apparent association with measured or observed soil or vegetation influences. Since there is no evidence telling which factors control the value of $\underline{a}$, the average of $\underline{a}$ = 0.62 was used together with the $\underline{n}$ = 1.387 to represent the average relationship illustrated in figure 5.

APPLICATION OF RESULTS

Pending basis for further refinement, practical application can be made of figure 5 as follows: (a) Estimate the final rate of infiltration from the soil array (2), (b) add it to the $f-f_c$ versus F_p relationship at points selected to define a curved-line relationship of f to F_p, and (c) apply these rates toward the depletion of the estimated volume of the infiltration potential.

Computations involved in the inter-depletion of rates and potential volume of storage are illustrated for three plots in table 3. Although the value of F_p was known in this case from the infiltrometer run, it is generally expressed as kS_r, i.e., the product of the vegetative factor and the available porosity remaining at any given time. Actually only the initial value of kS_r need be determined. Subsequent values can be computed for assumed increments of infiltration (ΔF). A corresponding rate of infiltration (f) is computed by the equation:

$$f = 0.62kS_r^{1.387} + fc$$

Wherein: f = rate of infiltration in inches per hour.

k = vegetative factor from figure 3.

S_r = available porosity as depleted by infiltrated volumes, in inches.

f_c = final constant rate of infiltration in inches per hour.

The average rate of infiltration is applied to each increment of volume to derive the time increment, (Δ t). The curves plotted from data computed in table 3 compare quite well (figure 6) with those observed with the infiltrometer on plots 1 and 7.

TABLE 3.--Reproduction of infiltration curves observed with infiltrometer

kS_r (inches)	ΔF (inches)	f (in./hr.)	f_a (in./hr.)	Δt (hours)	T (hours)	F (inches)
Plot No. 1, Alfalfa, run of 7-17-40, kS_o = 1.73, f_c = 0.15						
1.73	0	1.58			0	0
1.50	.23	1.24	1.41	0.16	.16	.23
1.00	.50	.77	1.00	.50	.66	.73
.50	.50	.38	.58	.86	1.52	1.23
0	.50	.15	.26	1.92	3.44	1.73
Plot No. 7, Lespedeza & timothy, run of 9-18-40, kS_o = 2.04, f_c = 0.36						
2.04	0	2.01			0	0
1.50	.54	1.45	1.73	0.31	.31	.54
1.0	.50	.98	1.22	.41	.72	1.04
.5	.50	.60	.79	.63	1.35	1.54
0	.50	.36	.48	1.04	2.39	2.04
			.36			
Plot No. 11, Bluegrass, run of 9-30-40, kS_o = 5.72, f_c = 0.10						
5.72		7.10			0	
5.0	0.72	5.90	6.50	0.11	.11	0.72
4.0	1.0	4.35	5.12	.20	.31	1.72
3.0	1.0	2.95	3.65	.27	.58	2.72
2.0	1.0	1.73	2.34	.43	1.01	3.72
1.0	1.0	.73	1.23	.81	1.82	4.72
0	1.0	.10	.42	2.38	4.20	5.72
			.10			

Key:
kS_r = potential infiltration to time of constant rate.
ΔF = increment of infiltration.
f = rate of infiltration associated with kS_r.
f_a = average rate of infiltration.
Δt = time increment = F/f_a
T = accumulated time.
F = accumulated infiltration.

Figure 7 portrays a situation wherein the computed curve of infiltration capacity may be of material assistance in analyzing infiltrometer data to obtain estimates of infiltration capacity during periods when the rate of rainfall is less than the infiltration capacity of the soil. By matching the computed rate curve to those portions of the observed curve during the later periods when rainfall was known to exceed the infiltration capacity, the computed curve provides a projection of what the capacity rate would have been during the initial portion of the run if rainfall had been adequate.

The type F infiltrometer, using a 6- by 12-foot plot, has previously been demonstrated to give results comparable to natural rainfall (8). As a further test of the applicability of principles derived from analyses of these data to field scale hydrology, curves of infiltration capacity were computed for three soils for which adequate data were available (4, 5). Pertinent characteristics of Kirvin fine sandy loam, Shelby silt loam, and Clinton silt loam are given in table 4. Profile descriptions of these soils indicate the restricting horizon. The final constant rate of infiltration would logically be associated with this layer, hence, available porosity was estimated for only those horizons lying above it.

Since antecedent moisture was not known, it was not possible to check individual storms. Therefore, the infiltration capacity was computed for the two extreme conditions, saturated and dry. Under saturated conditions infiltration capacity is assumed equal to the final constant rate. The constant rates in table 4 were derived from analyses of rainfall and runoff data. However, they do not differ greatly from those estimated for these soils from Musgrave's soil array (6). Available porosity for the dry condition was estimated, in table 4, as the difference between total porosity and the moisture content at the wilting point. Porosity below the wilting point was considered to be available only through capillary movement, probably at a rate something less than f_c.

Computations of the infiltration capacity curves for the dry condition of these soils are given in table 5. Available porosity derived in table 4 was modified by the pertinent vegetation factor $\underline{k}$ determined from figure 3 to estimate the potential volume of infiltration to the time of constant rate. Woods, on the Kirvin soil, were considered equal to or better than bluegrass; hence, $\underline{k}$ was assumed equal to 100 percent. Rotation hay, on the Clinton soil, was considered comparable to lespedeza and timothy, i.e., $k = 45$ percent. With k, S_o, and f_c determined, the computations follow the same procedure as was outlined for table 3. Curves derived in table 5 are plotted in figure 8.

Records of rainfall and runoff from these soils at Tyler, Texas (9), Bethany, Missouri (10), and LaCrosse, Wisconsin (2), respectively, were analyzed to estimate infiltration on watersheds of several acres area. The points plotted in figure 8 represent observed differences between rainfall and runoff plotted versus the total hours of opportunity, i.e., hours of rainfall. The computed extremes essentially bracket the observed values. Points lying in between presumably represent antecedent moisture conditions intermediate to saturation and the wilting point.

TABLE 4.--Soil characteristics for computing infiltration capacity 1/

Location	Soil	Depth (inches)	Description of texture	Total 2/ porosity minus wilt. pt. (inches)	S_o (inches)	f_c 3/ (in./hr.)
Tyler, Tex.	Kirvin fine sandy loam	0 - 12	Loamy fine sand	3.35	3.35	
		12 - 24	Brick red clay			0.17
		24 - 51	do			same
Bethany, Mo.	Shelby silt loam	0 - 10	Silt loam	2.58	2.58	
		10 - 15	Clayey Compact subsoil			0.03
		15 - 23	Sticky plastic clay			same
LaCrosse, Wis.	Clinton silt loam	0 - 8	Heavy silt loam	2.95		
		8 - 20	do	3.37	6.32	
		20 - 32	More compact subsoil			0.16

1/ Data from USDA Technical Bulletins 316 and 430 and SCS-TP for location.
2/ Data for composite samples uses.
3/ From analyses of runoff data.

TABLE 5.--Computation of capacity infiltration starting at wilting point soil moisture; by formula, $f = 62kS_r^{1.387} + f_c$

kS_r (inches)	ΔF (inches)	f (in./hr.)	f_a (in./hr.)	Δt (hours)	T (hours)	F (inches)
Kirvin fine sandy loam, plot GS-3, Tyler, Tex.; woods, k = 100 percent S_o = 3.35 inches, f_c = 0.17 in/hr						
3.35	0	3.47		0	0	0
3.00	.35	3.02	3.24	.11	.11	.35
2.50	.50	2.37	2.70	.19	.30	.85
2.00	.50	1.80	2.08	.24	.54	1.35
1.50	.50	1.26	1.53	.33	.87	1.85
1.00	.50	.79	1.02	.49	1.36	2.35
0.50	.50	.40	.60	.84	2.20	2.85
0	.50	.17	.28	1.78	3.98	3.35
Shelby silt loam, plot pa-B, Bethany, Mo.; Bluegrass, k ≐ 100 percent, S_o = 2.58 inches, f_c = 0.03 in/hr						
2.58	0	2.40			0	0
2.00	.58	1.66	2.03	0.29	.29	.58
1.50	.50	1.12	1.39	.36	.65	1.08
1.00	.50	.65	.88	.57	1.22	1.58
.50	.50	.24	.44	1.14	2.36	2.08
0	.50	.03	.14	3.57	5.93	2.58
Clinton silt loam, unterraced cultivated watershed, LaCrosse, Wis.; Rotation Hay, k est. 45%, S_o = 6.32 inches, f_c = 0.16 in/hr						
2.84		2.80			0	0
2.50	0.34	2.36	2.58	0.14	.14	.34
2.25	.25	2.06	2.21	.11	.25	.59
2.00	.25	1.78	1.92	.13	.38	.84
1.75	.25	1.50	1.64	.15	.53	1.09
1.50	.25	1.25	1.38	.18	.71	1.34
1.00	.50	.78	1.02	.49	1.20	1.84
0.50	.50	.40	.59	.85	2.05	2.34
0	.50	.16	.28	1.79	4.84	2.84

See key of table 3 for symbols.

LITERATURE CITED

(1) Baver, L. D.
1956. Soil physics. Third edition. 489 pp., illus., New York and London.

(2) Hays, O. E. and Atkinson, H. B.
1939. Compilation of rainfall and runoff from the watersheds of the upper Mississippi Valley conservation experiment station, LaCrosse, Wisconsin, 1932-38. Hydrologic studies. U. S. Dept. Agr., SCS TP 29, illus.

(3) Lyon, T. L., Buckman, H. O. and Brady, N. C.
1952. The nature and properties of soils. Fifth edition. 591 pp., illus., New York.

(4) Middleton, H. E., Slater, C. S. and Byers, H. G.
1932. Physical and chemical characteristics of the soils from the erosion experiment stations. U. S. Dept. Agr., Tech. Bul. 316, 51 pp., illus.

(5) ______________, ______________, ______________
1934. The physical and chemical characteristics of the soils from the erosion experiment stations--second report. U. S. Dept. Agr., Tech. Bul. 430, 62 pp., illus.

(6) Musgrave, G. W.
1955. How much of the rain enters the soil? U. S. Dept. Agr. Yearbook, 151-159 pp., illus.

(7) Philip, J. R.
1957. The theory of infiltration. Soil Science, 83 (5 and 6): 345-357, 435-448; 84 (1, 2, and 3): 163-178, 257-264, 329-339, illus.

(8) Sharp, A. L., Holtan, H. N. and Musgrave, G. W.
1949. Infiltration in relation to runoff on small watersheds. U. S. Dept. Agr., SCS TP 81, 40 pp., illus.

(9) Word, O. C., Jr.
1941. Compilation of rainfall and runoff data from the watersheds of the Ark.-La.-East Texas sandy lands conservation experiment station, Tyler, Texas, 1931-39. Hydrologic studies. U. S. Dept. Agr., SCS TP 41, illus.

(10) Zingg, A. W.
1941. Compilation of rainfall and runoff from the watersheds of the shelby loam and related soils, conservation experiment station, Bethany, Missouri, 1933-40. Hydrologic studies. U. S. Dept. Agr., SCS TP 39, illus.

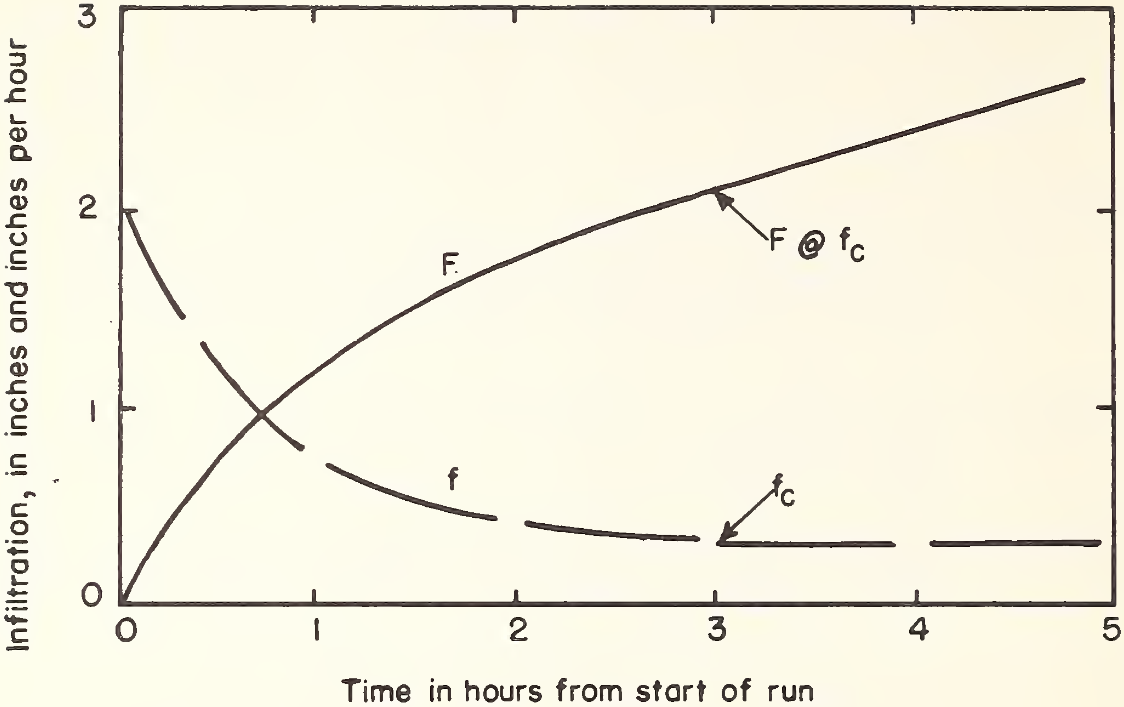

Figure 1.--Determination of infiltration volume (F) to time the rate (f) becomes constant (f_c), - infiltrometer plot No. 16, Edwardsville, Ill.

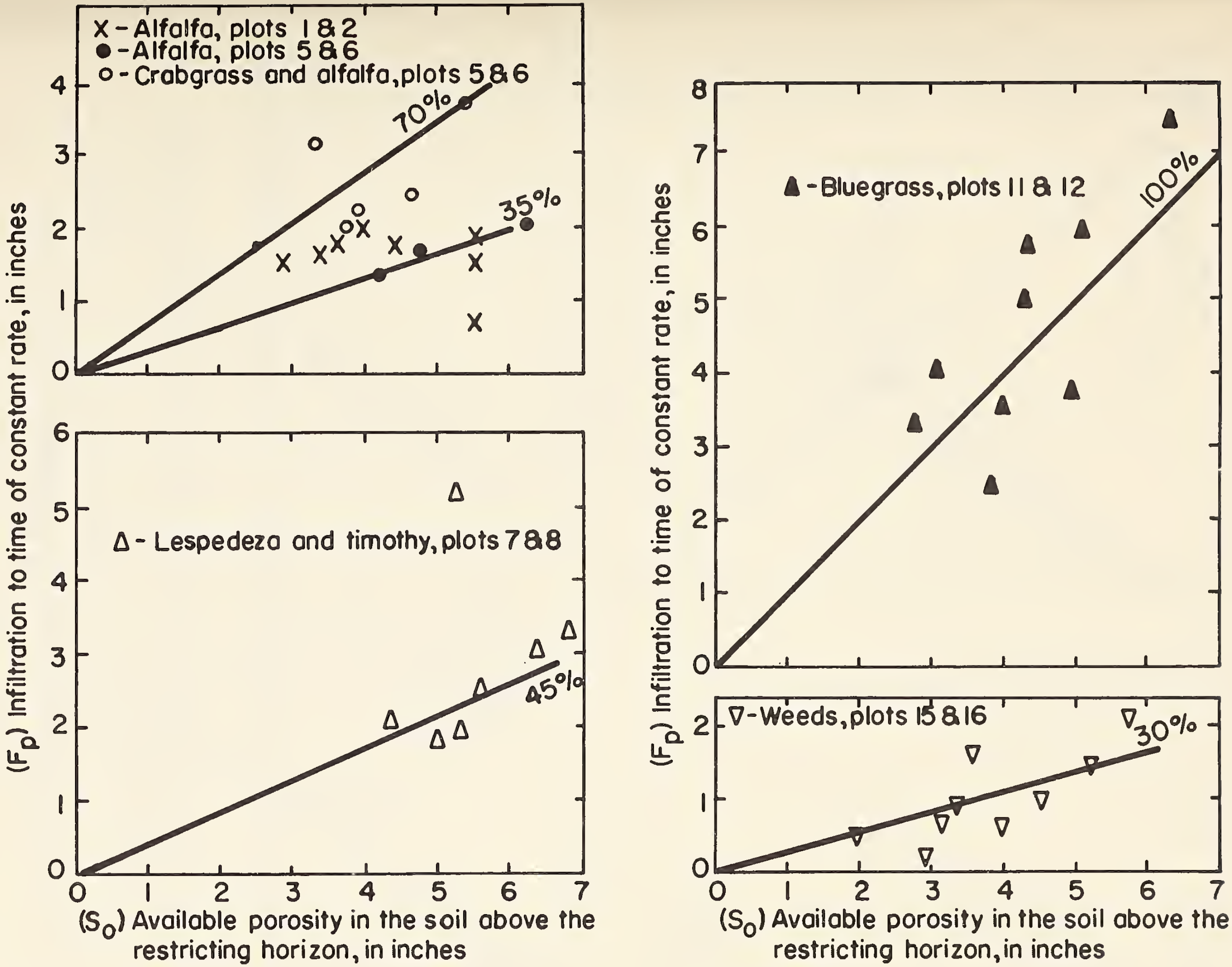

Figure 2.--Infiltration to time of constant rate compared to available porosity in the soil above the restricting horizon.

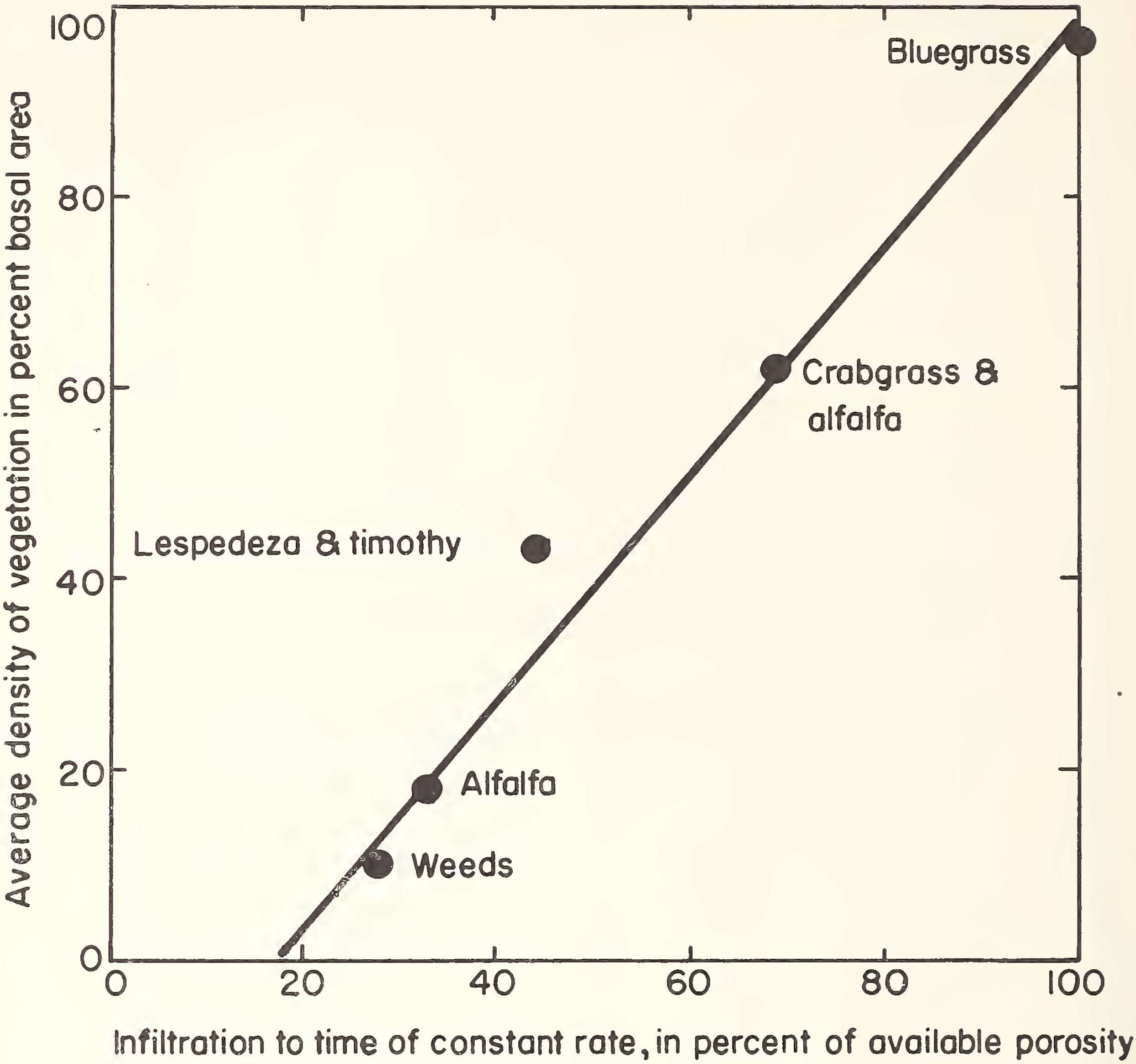

Figure 3.--Density of vegetation as an index of the portion of available porosity, which will be filled before the infiltration rate becomes constant.

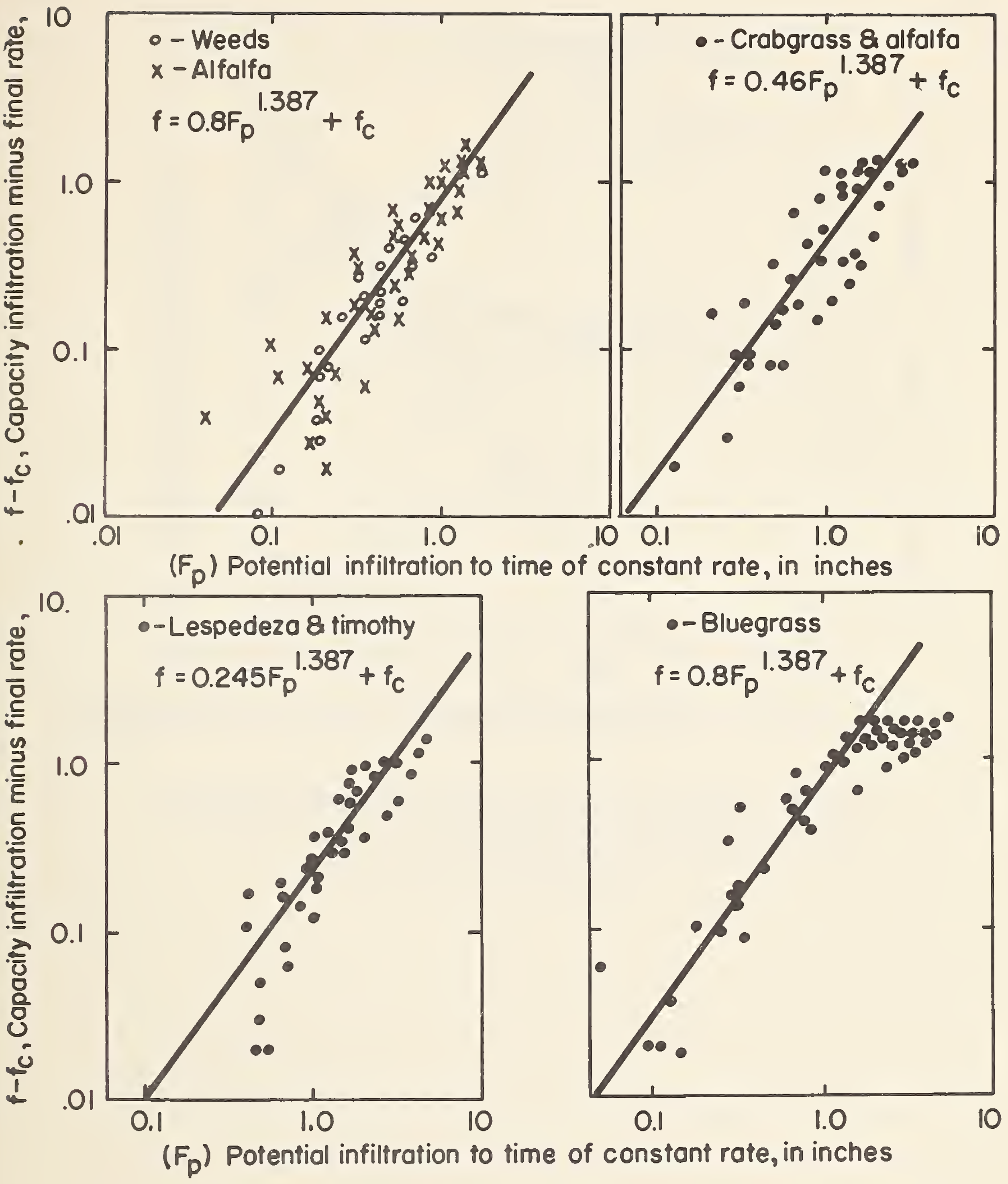

Figure 4.--Relationships between capacity rate and potential volume of infiltration before the rate becomes constant.

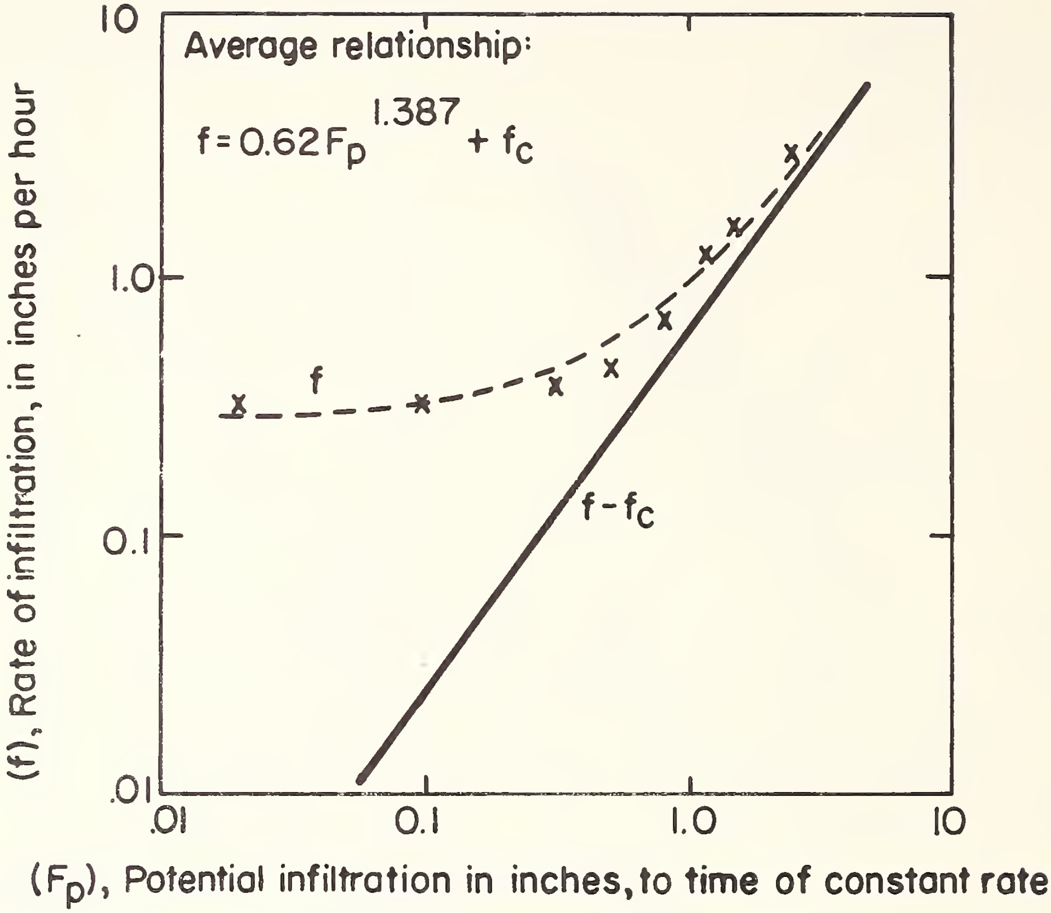

Figure 5.--Average relationship of capacity rate and the potential volume of infiltration before the rate becomes constant.

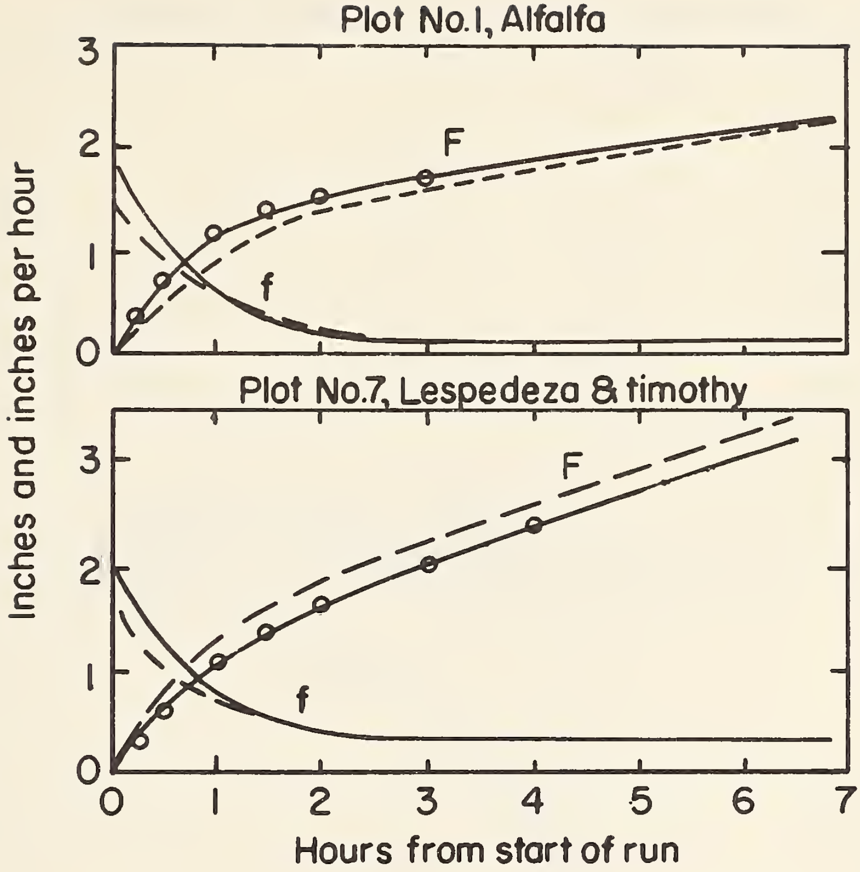

Figure 6.--Computed (dashed line) and observed (solid line) capacity infiltration on infiltrometer plots 1 & 7, Edwardsville, Ill. (See footnotes table 1 for symbols.)

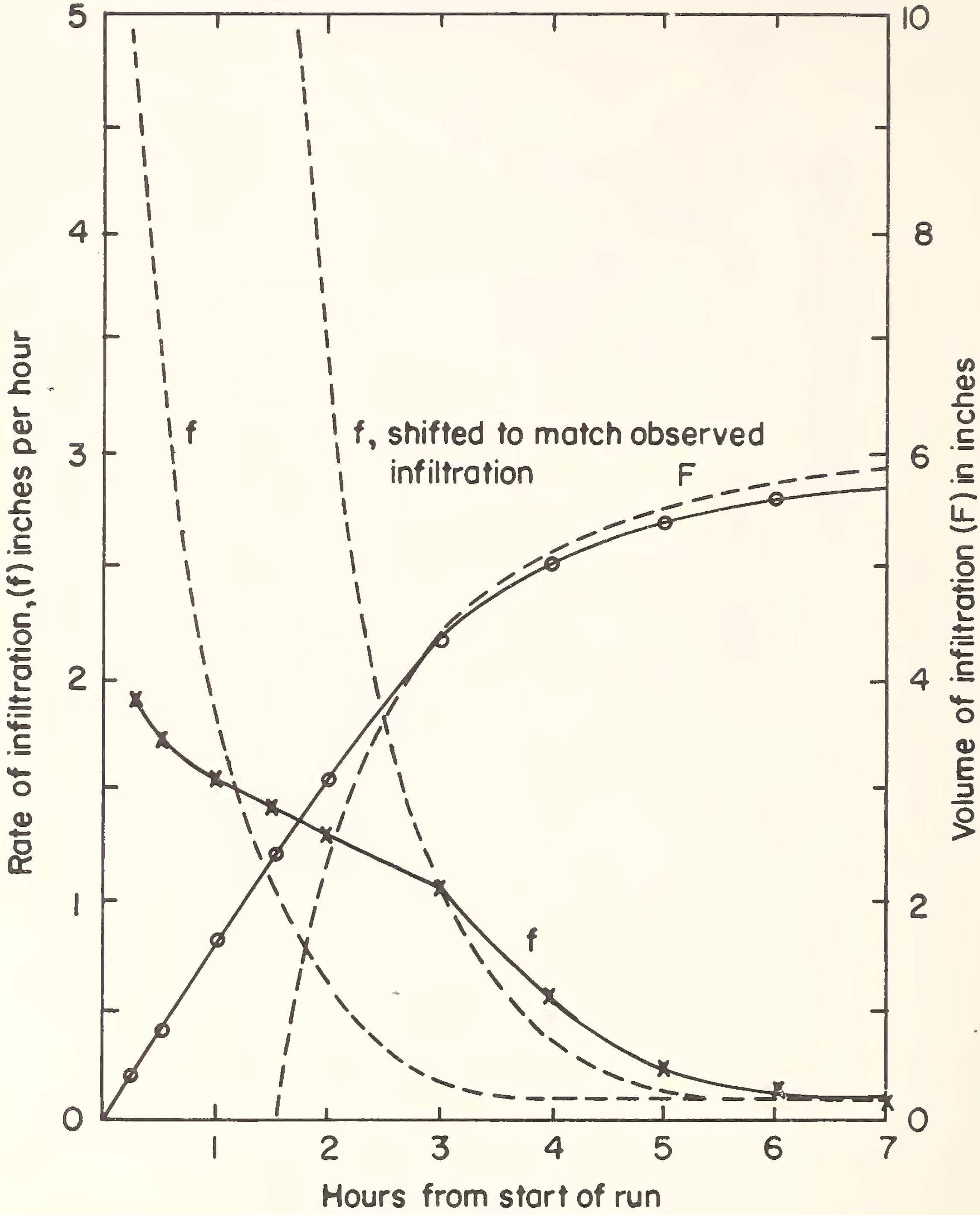

Figure 7.--Computed capacity infiltration (dashed line) and observed infiltration as limited by rainfall (solid line), infiltrometer plot No. 11, Bluegrass, Edwardsville, Ill. (See footnotes of table 1 for symbols.)

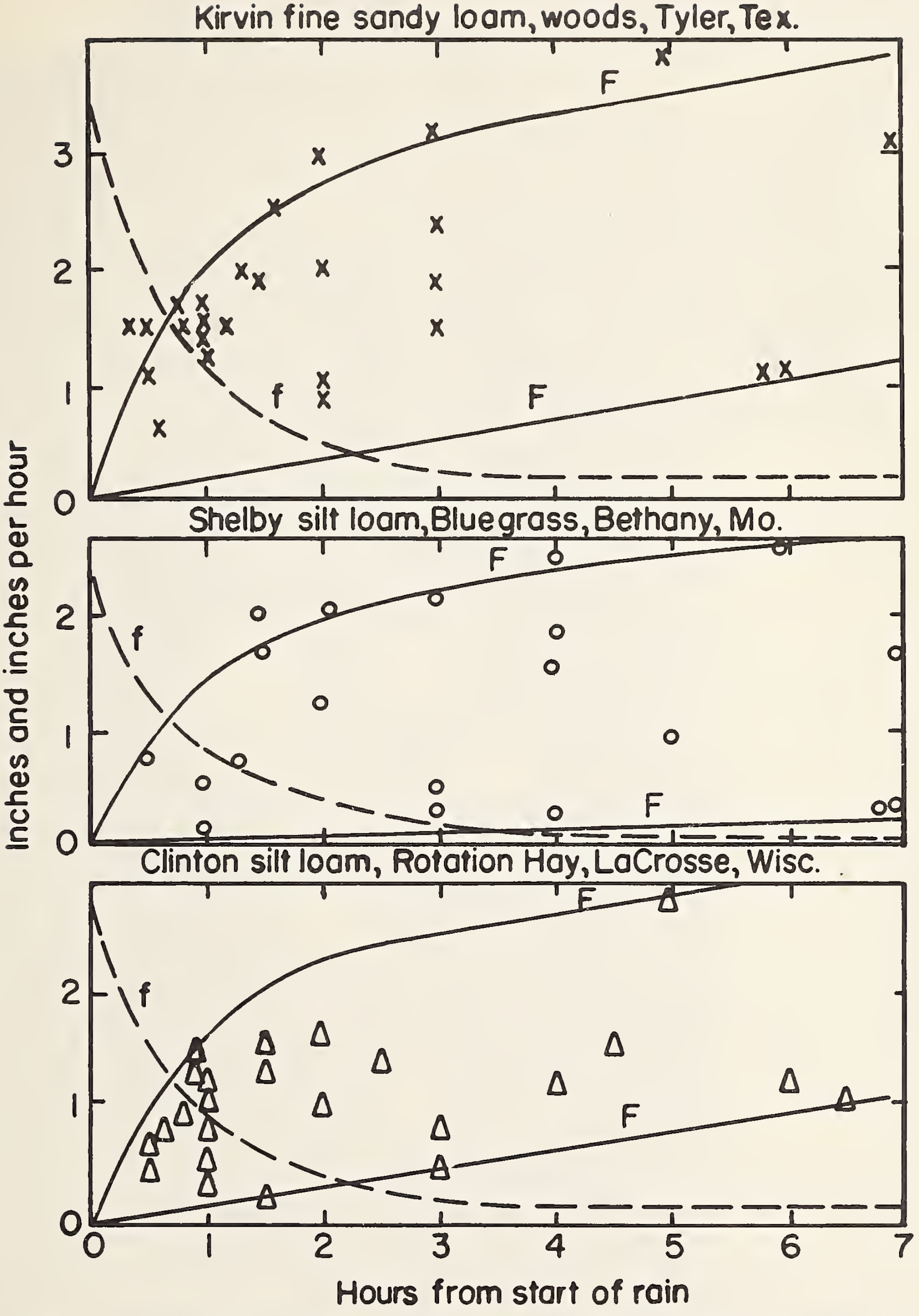

Figure 8.--Computed upper and lower limits (solid lines) of capacity infiltration compared to observed amounts (plotted points) on three soils. The dashed line is the computed upper limit of the rate of infiltration.